METHOD AND APPARATUS FOR SUPPLYING REFRIGERANT FLUID

Field of the Invention

The present invention may relate to supplying refrigerant fluid to, for example, a cooling device for generating a cooling effect based on Joule-Thompson expansion of the fluid. The invention may be especially useful in the field of medical or surgical use. The cooling device may, for example, be a cooling probe.

Background to the Invention

The Joule-Thompson principle of isenthalpic expansion of certain refrigerant fluids (e.g., gases) through a micro expansion orifice has long been used in the medical field to create a freezing effect. Typically, the expansion orifice is located at the tip of a probe through which the refrigerant fluid is driven under pressure. The operation of the probe is controlled by a fluid supply apparatus including one or more valves or regulators for controlling the flow of fluid in the probe. A conventional fluid supply apparatus is described, for example, in WO 00/35362.

A significant problem is that the micro expansion orifice in the probe is vulnerable to blocking by foreign matter such as dust particles or other contaminants that may be contained in the refrigerant fluid or otherwise enter the probe. A blocked probe normally has to be returned to a service center or factory for thorough cleaning before the probe can be used reliably again. For many cyro-surgeons and probe operators, the problem of probe blocking is

considered to be a highly inconvenient, yet regular, occurrence that has to be tolerated as a result of the nature of the probe design.

Other problems remain in terms of difficulty of use of the fluid supply apparatus and the probe, difficulty of handling fault conditions such as a blocked or faulty probe, and difficulty of reducing the risk of occurrence of probe blockage.

Summary of the Invention

A first aspect of the present invention may be to provide an at least momentary backflushing of fluid through a cooling device. The backflushed fluid may be the same fluid as that used as the refrigerant. The backflushing may be effective to clear or dislodge any foreign matter that may have been driven into an expansion orifice of the cooling device by the usual flow of fluid in the forward direction.

The backflushing may be controlled by an arrangement of valves. The valves may be configured in a first mode of operation in which refrigerant fluid may be caused to flow in a forward direction through the cooling device. The valves may further be configured in a second mode of operation in which fluid may be caused to flow, at least momentarily, in a reverse direction through the cooling device. In one form, the second mode may be a mode in which the cooling device may be pressurized such that pressure may develop in both an inlet side and outlet side of the cooling device, whereafter the inlet side may be vented to cause pressurized fluid on the outlet side to backflush through

the cooling device. Such a configuration may generate an abrupt pressure differential or pressure wave that may be extremely effective to dislodge foreign matter blocking the cooling device.

The backflushing may be carried out when a blockage is detected in use. Additionally or alternatively, the backflushing may be carried out routinely at intervals in use of the cooling device. For example, the backflushing may be carried out following each freeze and/or thaw cycle (or each combined freeze-thaw cycle) of the cooling device. Such frequent backflushing has been found to be highly effective in reducing the risk of occurrence of a blockage, even if the cooling device is used many times.

A second aspect of the invention may be to use, as a valve between a high pressure refrigerant fluid source, and an inlet side of a cooling device, a valve that is responsive to a pulse modulated electronic control signal. The pulse modulated signal may be a pulse width modulated signal (PWM), or a pulse density modulated (PDM) signal. A pulsed valve may have a fast response, and be less expensive and yet more reliable and durable than an equivalent servo driven valve.

A third aspect of the invention may be to implement an automatic gradual application of pressure to an inlet side of a cooling device, instead of an abrupt application of refrigerant fluid at high pressure. Such a gradual application of pressure may be referred to as a "soft start". The gradual application of pressure may help reduce the risk of blockage in the cooling device by avoiding an

abrupt pressure wave in the forward direction through the cooling device that may otherwise force foreign matter on the inlet side of the cooling device into the expansion orifice.

A fourth aspect of the invention may be for a control unit of the fluid supply apparatus to be provided with one or more program sequences each of one or more freeze-thaw cycles. The control unit may be responsive to a manual start command from an operator to begin performing a selected program sequence. Thereafter, the control unit may be configured to automatically advance through the program sequence without any further input from the operator. The control unit may be responsive to an interrupt command from the operator to enable the program sequence to be halted at any moment if desired by the operator.

A fifth aspect of the invention may be to measure the flow rate of refrigerant fluid passing through the cooling device, at least in one or more certain modes of operation of the cooling device. A flow rate sensor may be coupled to a low pressure side of the cooling device. Coupling the flow rate sensor on the low pressure side may enable a less expensive flow rate sensor to be used.

The measured flow rate may be used to detect the occurrence of a blockage in the cooling device. For example, a blockage may be identified when the flow rate is zero or unusually small. In response to a detected blockage, a warning signal may be generated. Additionally or alternatively, a self-unblocking operation may be initiated to try to clear the blockage. The self-unblocking operation

may include backflushing fluid through the cooling device in an opposite direction to the normal flow during cooling.

The measured flow rate may also, or alternatively, be used in combination with a measured fluid pressure and/or temperature, in a feedback loop for regulating the fluid pressure applied to the cooling device in order to control the performance of the cooling device.

Other features, objects and advantages of the invention may be defined in the claims and/or apparent from the following description of a preferred embodiment of the invention.

Brief Description of the Drawings

A non-limiting preferred embodiment of the invention is now described by way of example with reference to the claims and accompanying drawings in which:

Fig. 1 is a schematic diagram of fluid and control circuitry for a refrigerant fluid supply apparatus;

Fig. 2 is a schematic flow diagram illustrating operating modes of the fluid supply apparatus;

Figs. 3-6 are schematic flow diagram illustrating details of Fig. 2;

Figs. 7 and 8 are schematic representations of preset freeze-thaw programs;

Fig. 9 is a schematic flow diagram illustrating performance of a predefined sequence of free-thaw cycles; and

Figs. 10(a)-(c) are schematic representations of a valve control signal useable in the apparatus of Fig. 1.

Detailed Description of the Preferred Embodiment

Fig. 1 may generally illustrate a fluid supply apparatus 10 for supplying and controlling the flow of a refrigerant fluid to a cooling device 12. The cooling device 12 may be detachably connectible to a coupling 18 of the apparatus 10. The cooling device 12 may be a medical or surgical probe. The cooling device 12 may include a small orifice (depicted schematically at 14) for generating a freezing effect by the Joule-Thompson principle of isenthalpic expansion when fluid is forced through the orifice 14 from an inlet side 12a to an outlet side 12b. The terms "inlet side" and "outlet side" may refer to a normal direction of fluid flow through the cooling device 12 for generating the intended freezing effect. The refrigerant fluid may be any suitable fluid for generating significant cooling upon isenthalpic expansion. Such a fluid may often be referred to as a Joule-Thompson fluid and may be a gas. For example, the gas may be nitrous oxide.

The supply apparatus 10 may generally comprise a first arrangement of valves V1-V4 for controlling a flow of the refrigerant fluid through (e.g. to and/or from) the cooling device 12, and a second arrangement of valves V5-V8 for selecting an active one of a plurality of sources 15a-d of the refrigerant fluid to supply to a fluid supply node 16 in

the apparatus. The normal fluid pressure from the active source 15a-d at the fluid supply node 16 may typically be between 650 and 900 psi.

In more detail, a first valve (or "freeze valve") V1 may be coupled between the fluid supply node 16 and a first coupling port (e.g., first coupling conduit) 18a to the inlet side 12a of the cooling device 12. The first valve V1 may supply fluid to the coupling port 18a. A second valve (or "purge valve") V2 may be coupled between the fluid supply node 16 and a second coupling port 18b (e.g., second coupling conduit) to the outlet side 12b of the cooling device 12. The second valve V2 may supply fluid to the second coupling port 18b. A pressure reducing resistance or constriction or shunt 20 may be coupled in series with the second valve V2 for reducing the pressure in response to fluid flow through the second valve V2. The first and second valves V1 and V2 may collectively be referred to as "supply valves" for delivering pressurized fluid to the inlet and outlet sides 12a, and 12b, of the cooling device 12.

A third valve (or "inlet vent valve") V3 may be coupled between the first coupling port 18a and an exhaust port 22 for venting spent fluid from the apparatus. The third valve V3 may selectively vent the first coupling port 18a independently of the second coupling port 18b. A fourth valve (or "exhaust vent valve") V4 may be coupled between the second coupling port 18b and the exhaust port 22. The fourth valve V4 may selectively vent the second coupling port 18b independently of the first coupling port 18a. Although a single exhaust port 22 may be illustrated, the

third and fourth valves V3 and V4 may alternatively be coupled to different exhaust ports or vents. A flow rate sensor F may be coupled in series with the fourth valve V4 for measuring the flow through the fourth valve V4. The flow rate sensor may be coupled via the fourth valve V4 to the second coupling port 18b, which may be referred to as a low pressure side of the cooling device 12. The flow rate sensor F may be coupled between the exhaust port 22 and the fourth valve V4 so that the fourth valve V4 may be used to isolate the flow rate sensor F from an excessive pressure. A parallel shunt 24 may be coupled in parallel with the flow rate sensor F, for enabling the flow rate sensor F to be used to sense a higher flow rate than the through-flow capacity of the flow rate sensor F alone. The flow rate sensor F may enable the flow of fluid through the cooling device 12 to be monitored, so that any occurrence of a blockage may be detected. The third and fourth valves V3 and V4 may collectively be referred to as "vent valves" for venting the inlet and outlet sides 12a and 12b of the cooling device 12.

The first and second valves V1 and V2 may be normally-closed valves. The third and fourth valves V3 and V4 may be normally-open valves. Such an arrangement may provide a fail-safe mode, should any of the valves fail. The first and second valves V1 and V2 may fail-safe closed, such that refrigerant fluid is shut off by each valve. The third and fourth valves V3 and V4 may fail-safe open, such that the any fluid pressure in the cooling device 12 may be vented through the exhaust port 22.

An electronic control unit 26 may generate respective control signals VCS1, VCS2, VCS3 and VCS4 for controlling the valves V1-V4. The electronic control unit 26 may receive a flow rate signal FS generated by the flow rate sensor F. The electronic control unit 26 may also receive first and second pressure signals PS1 and PS2 from first and second fluid pressure sensors P1 and P2. The first pressure sensor P1 may be coupled to sense the fluid pressure at the fluid supply node 16. The first pressure signal PS1 may provide a direct indication of the fluid supply pressure from the active supply source, as described later. The second pressure sensor P2 may be coupled to sense the fluid pressure at the first coupling port 18a. The second pressure signal PS2 may provide an indication of the pressure applied to the cooling device 12 in normal use, and may also be used to pressure-test the cooling device 12 to detect leaks, as described later.

The electronic control unit 26 may further receive one or more input and/or command signals from a remote control device 28. The remote control device may, for example, be a foot switch. An advantage of a foot switch is that an operator may control the apparatus 10 without contaminating his or her hands, if the operator requires sterile conditions to be maintained. The electronic control unit 26 may further receive one or more input and/or command signals from input switches 30 mounted on a control panel of the apparatus 10. The electronic control unit 26 may further receive a temperature signal from a temperature sensor (not shown) if such a temperature sensor is provided in the cooling device 12.

Referring to Fig. 2, the control unit 26 may control the apparatus 10 in one or more operation modes. The modes may include rest mode 31, a pressure test mode 32, a purge mode 34, a freeze or cooling mode 36, a thaw or heating mode 38, a backflush mode 40 and/or an unblock mode 59. The rest mode 31 may correspond to the fail-safe condition of the first to fourth valves V1-V4. The operation cycles of the apparatus 10 may begin and/or end (e.g., loop back to) the rest mode 31.

When a cooling device 12 may be connected to the coupling 18, the control unit 26 may firstly initiate the test mode 32 to test whether the cooling device is adequately pressure tight. Referring to Fig. 3, at step 42 the first to fourth valves V1-V4 may all set to their closed condition. At step 44, the first valve V1 and/or the second valve V2 may be opened to pressurize the cooling device 12 from the fluid supply node 16. The cooling device may be pressurized to the full pressure of the fluid supply node 16. The first valve V1 and/or second valve V2 may be held open for a predetermined period of time, or until the pressure measured by the second pressure sensor P2 may have stabilized. At step 46, the pressure measured by the second pressure sensor P2 may be recorded, and the first valve V1 and/or second valve V2 may again be closed, so that the cooling device 12 is again isolated, but in a pressurized state. At step 48, after a predetermined test duration, the pressure measured by the second pressure sensor P2 may again be recorded, and compared with the previously recorded value. When the two pressure values are the same (or differ by less than a certain allowable tolerance), the cooling device 12 may be considered to be adequately pressure tight, and acceptable

for use. When the two pressure values are not the same (or differ by more than the allowable tolerance), the cooling device 12 may be considered to be leaky. In the case of a leaky device, the control unit 26 may inhibit any further operation with that cooling device 12. A leaky device may be potentially unsafe. For example, there may be risk that leaked refrigerant fluid may enter a patient's blood stream should the cooling device be used on a patient, or there may be risk of the cooling device 12 losing structural integrity.

After step 48, the pressure in the cooling device 12 may be vented at step 50 by opening the third valve V3 and/or the fourth valve V4. The third valve V3 may be opened before the fourth valve V4 in order to allow most of the pressure to vent through the third valve V3 before the fourth valve V4 is opened. Opening the third valve V3 before the fourth valve V4 may protect the flow rate sensor F from an excessive flow rate outside its normal range. Opening the third valve V3 before the fourth valve V4 may also generate an at least momentary backflushing of high pressure fluid through the cooling device 12 (for example, fluid under pressure on the outlet side 12b may flow in a reverse direction through the orifice 14 to vent via the inlet side 12a). Such high pressure and/or abrupt backflushing of fluid has been found to be extremely useful to clear any foreign matter at least from the vicinity of the orifice 14 of the cooling device 12, and hence reduce the risk of blockage at the orifice 14.

When the cooling device 12 may have successfully passed the pressure test 32, the operation may loop back to the rest

mode 31 before the purge mode 34 is invoked, or may proceed immediately to a purge mode 34. The purge mode 34 may be effective to remove accumulated moisture from the cooling device 12. Referring to Fig. 4, at step 52, all of the first to fourth valves V1-V4 may initially be set closed. At step 54, the second valve V2 and the third valve V3 may be opened, to create a flow of fluid from the fluid supply node 16 via the second valve V2 and the pressure reducing shunt 20 to the outlet side 12b of the cooling device 12. The flow of fluid may be vented from the inlet side 12a of the cooling device, through the third valve V3 to the exhaust port 22. In the purge mode 34, the pressure of the fluid may be reduced to a modest level by the effect of the pressure reducing shunt 20 while fluid is flowing. The modest pressure level may, for example be less than 300 psi, or less than 250 psi. The flow may be maintained for a predetermined period of time effective to purge moisture from the apparatus 10 and the cooling device 12. At the end of the purge mode, the flow of fluid may be halted at step 56 by closing the second valve V2. The fourth valve V4 may be opened at step 58 to vent any residual pressure on the outlet side 12b of the cooling device 12.

Following the purge mode 34, the operation may return to the rest mode 31 awaiting a command to begin a freeze-thaw operation. In a freeze-thaw operation, the control unit 26 may initiate one or more cycles of the freeze mode 36, thaw mode 38 and backflush mode 40. The cycle may, for example, be initiated in response to a command from the remote control unit 28. Referring to Fig. 5, the freeze mode 36 may be entered at step 60 by setting the second and third valves V2 and V3 shut, and by opening the first and fourth

valves V1 and V4. Fluid at high pressure may flow from the fluid supply node 16 via the first valve V1 to the inlet side 12a of the cooling device 12. The high pressure fluid may flow in the forward direction through the orifice 14, creating cooling by the Joule-Thomson effect. The expanded fluid may vent from the outlet side 12d of the cooling device via the fourth valve V4 and the flow rate sensor F to the exhaust port 22. The second pressure sensor P2 and the flow rate sensor F may provide useful indications of the state of the fluid flow and/or operation of the cooling device 12. In particular, the flow rate signal FS from the flow rate sensor F may provide a direct indication of whether fluid is flowing freely through the cooling device 12, or whether flow may be restricted or completely stopped, for example, by a blockage in the cooling device 12. When a blockage is detected, then the control unit 26 may invoke the unblock mode 51 (described below) to try to clear the blockage.

The duration of the freeze mode 36 may be predetermined by a preset program within the control unit 26, or it may be controlled manually by an operator, for example, by using the remote control device 28. At the end of the freeze mode 36, operation may proceed to the thaw mode 38. At step 62, the fourth valve V4 may be closed to halt the venting of fluid from the outlet side 12b of the cooling device 12 through the exhaust port 22. A thaw or defrost effect may be generated in the cooling device 12 by progressive re-pressurization of the fluid trapped on the outlet side 12b of the cooling device 12. As an optional step 64, the second valve V2 may be opened to increase the rate of pressurization of the outlet side 12b, and hence generate a

more rapid thaw effect. The duration of the thaw mode 38 may be predetermined by a preset program within the control unit 26, or controlled manually by the operator (for example, using the remote control device 28).

Following the thaw mode 38, operation may proceed to the backflush mode 40. At step 66, the cooling device 12 may be isolated from the fluid supply node 16, but kept in the pressurized state. For example, at step 66, the first valve V1 may be closed to halt the supply of refrigerant fluid to the inlet side 12a of the cooling device 12. If at step 64 the second valve V2 may have been opened during the thaw mode 38, the second valve V2 may also be re-closed at step 66. At step 68, the third valve V3 may be opened to allow the trapped fluid to vent from the inlet side 12a of the cooling device 12. In a similar manner to step 50 described above, opening the third valve V3 may generate an at least momentary backflushing of fluid through the orifice 14, which has been found to be extremely effective for reducing the risk of blockage at the orifice 14. The backflush mode 40 may be used at the end of each freeze-thaw cycle. Such regular high-pressure backflushing can extend the usability of the cooling device 12 considerably compared to a conventional fluid supply apparatus which does not provide the same backflush operation. In particular, the cooling device 12 may be used numerous times without blocking, in contrast to the high risk of blocking when a cooling device is driven by a conventional gas supply apparatus.

After the backflush mode 40, operation may loop back to the freeze mode 36 if, for example, a sequence of multiple freeze-thaw cycles may be used as part of the same

treatment. A sequence of multiple freeze-thaw cycles may be controlled automatically be the control unit 26, or manually, for example, using the remote control device 28. After completion of the freeze-thaw cycles, the control unit 26 may return the apparatus to the rest mode 31.

As mentioned above, when a blockage is detected during the freeze mode 36, operation may branch to the unblock mode 59. The operation of the unblock mode 59 may be similar to the backflushing described previously for steps 50 and 68. Referring to Fig. 6, at step 70, the cooling device 12 may be pressurized to a high pressure, by opening the first valve V1 and/or the second valve V2 while closing the third valve V3 and the fourth valve V4. Then, at step 72, the fluid may be backflushed through the orifice 14 by opening the third valve V3 while closing at least the first valve V1. The second valve V2 may remain open or closed during backflushing. The fourth valve V4 may remain closed during the backflushing, to avoid any pressure loss on the outlet side 12b of the cooling device 12. After backflushing, the fourth valve V4 may be opened at step 74 to vent any residual pressure on the outlet side 12b. During step 74, the flow rate measured by the flow rate sensor F may be monitored to detect whether a significant amount of fluid may vent through the fourth valve V4. If the blockage has been cleared, then very little fluid may vent through the fourth valve V4. A large quantity of fluid venting through V4 may indicate that the blockage may not have been cleared. One or more backflush cycles may be performed in sequence to try to clear a blockage of the cooling device. Following the unblock mode 59, operation may return to the freeze mode 36. Alternatively, the control unit 26 may signal a warning

or a report to the operator to indicate that a probe blockage has occurred, and/or to indicate whether or not the blockage has been cleared.

In the foregoing description, backflushing may be achieved by pressurising both the inlet side 12a and the outlet side 12b of the cooling device 12, and opening the third valve V3 to vent the fluid from the inlet side 12a. Opening the third valve V3 while keeping the fourth valve V4 closed may generate an at least momentary flow of a quantity of pressurized fluid from the outlet side 12b through the orifice 14 to the inlet side 12a, thereby backflushing fluid through the orifice. The backflushing may generate an abrupt pressure burst or pressure wave across the orifice, which is extremely effective in clearing foreign matter from the orifice 14. The magnitude of a backflush pressure differential across the orifice may be at least, or greater than, any of: 300 psi, 350 psi, 400 psi, 450 psi, 500 psi, 550 psi, 600 psi, 650 psi, 700 psi, 750 psi, 800 psi, or 850 psi. As an alternative to a momentary flow, a separate back-flush valve V9 may be coupled from the fluid supply node 16 to the second coupling port 18b. The back flush valve V9 may be operated to provide a continuous flow of high pressure fluid to the outlet side 12b of the cooling device, for continuous backflushing through the orifice 14.

Referring to Fig. 1, the control unit 26 may comprise a storage device 80 for storing one or more program sequences of freeze-thaw cycles. The storage device 80 may be a non-volatile storage device. The storage device may, for example, comprise a non-volatile semiconductor memory, or magnetic or optical media. The program sequences may be

programmable by the operator, or predefined within the control unit 26. Fig. 7 may illustrate a first example format for storing the one or more program sequences 82a, 82b. Referring to Fig. 7, each program sequence 82a, 82b may include data representing at least durations 84 of a sequence of freeze modes 36 and thaw modes 38. The durations 84 may include freeze mode durations 84a and thaw mode durations 84b. In the first example format, separate data may be provided for each mode in the program sequence 82. Providing separate data may enable the duration of freezing and thawing to be varied at different parts of the sequence. For example, the first sequence 82a may define a first freeze cycle of 3 minutes, a second thaw cycle of 30 seconds, a third freeze cycle of 2 minutes, and a fourth thaw cycle of 20 seconds. The second sequence 82b may define a first freeze cycle of 3 minutes, a second thaw cycle of 30 seconds, a third freeze cycle of 3 minutes and a fourth freeze cycle of 30 seconds.

Fig. 8 may illustrate a second example format for storing one of more program sequences 86a, 86b in a special case in which the durations of the freeze modes 36 and thaw modes 38 may not vary throughout the program sequence. Referring to Fig. 8, each program sequence 86a, 86b may comprise data representing at least a duration 88a of a single freeze mode 36, a duration of a single thaw mode 38, and a number 88c of repetitions of the free-thaw cycles in the program sequence. For example, a first sequence 86a may define 2 repetition of cycles of a 3 minute freeze and a 30 second thaw. The first sequence 86a may be the same as the sequence 82b described with respect to Fig. 7. A second sequence may define 3 repetition cycles of a 3 minute freeze and a 30 second thaw.

The number of program sequences 82 or 86 may depend on a specific application for which the apparatus 10 is intended. For example, only a single program sequence 82 or 86 may be provided in some applications. An operator may select the single program sequence 82 or 86, or may select between plural program sequences 82 or 86, using the selectors 30. Referring to Fig. 9, once a program sequence has been selected, at step 90 the control unit 26 may be responsive to a "start" command from an operator. The "start" command may be inputted through one of the input switches 30 or through the remote control device 28. Once the "start" command has been received, operation may proceed to step 92 at which the selected program sequence may be retrieved from the storage device 80 and the defined freeze-thaw cycles of the program sequence may be performed. For example, the sequence of freeze-thaw cycles may be performed one after the other without any further inputs from the operator. During step 92, the control unit 26 may be responsive to an interrupt signal from the operator for halting the program sequence. The interrupt signal may be inputted through the input switches 30 or through the remote control device 28. When the interrupt signal is received, operation may proceed to step 94 at which the program sequence may be halted. For example, the first and second valves V1 and V2 may be closed, and the third and fourth valves V3 and V4 opened. The third valve V3 may be opened before the fourth valve V4, in order to protect the flow rate sensor F, in a similar manner to that described for step 50. Alternatively, at step 94, the thaw mode 38 may be invoked in order to immediately reverse any freezing at the cooling device 12. The automatic performance of a program sequence may enable

the operation of the cooling device 12 and the supply apparatus 10 to be simplified, and enable surgeons not familiar with manually operation to use the apparatus 10 with ease. Moreover, when the remote control device 12 may be used to provide the start command and/or the interrupt command, the operator need not contaminate his or her hands if sterile conditions are preferred. This may enable a procedure to be carried out by a single person, rather than involving one person to hold and position the cooling device (in sterile conditions) and another person to manipulate the controls of the refrigerant supply apparatus.

Referring again to Fig. 1, each of the fluid supply sources 15a-d may comprise a replaceable fluid cylinder. The cylinders may be mountable within the apparatus 10. Each source 15a-d may be coupled via a non-return valve 100a-d and a filter 102a-d to a respective one of fifth, sixth, seventh and eighth valves V5-V8, respectively. The fifth to eighth valves V5-V8 may be coupled to the fluid supply node 16 to enable fluid to be drawn from a selected one of the sources 15a-d, and fed to the fluid supply node 16. A function of the filters 102a-d may be to remove at least some dust particles or other foreign matter from the supplied fluid, in order to reduce the risk of blockage of the cooling device 12. The control unit 26 may be responsive to the pressure measured by the first pressure sensor P1 to determine the state of a currently selected one of the sources 15a-d. When the pressure may drop below a predetermined threshold indicative of the source 15a-d running nearly empty, the control unit 26 may operate respective valves of the fifth to eighth valves V5-V8 to automatically decouple the depleted source, and to select

instead another source. Such automatic operation may be performed while fluid is being supplied to the cooling device 12, so that the operation of the cooling device 12 may not be interrupted.

The components within the broken line 104 of Fig. 1 may conveniently be mounted on an integral manifold unit (not shown) having conduit bores and chambers for forming the fluid flow paths indicated in Fig. 1.

The first to eighth (or ninth) valves V1-V8 (and V9) may be electrically operated valves. The valves may, for example, be solenoid operated valves. The first valve V1 may be configured to have a variable aperture, to provide a variable flow control between a fully open condition and a fully closed condition. For example, the first valve V1 may be a variable servo controlled valve. Alternatively, the first valve V1 may be of a type intended to be driven by a modulated signal for controlling the first valve V1 according to a degree of modulation. For example, referring to Fig. 10, the first control signal VCS1 may be a pulse modulated signal. The pulse modulated signal may be a pulse width modulated (PWM) signal. The degree of opening of the first valve V1 may be controlled by a duty ratio of the PWM signal. Fig. 10a may illustrate a first example of the control signal VCS1 having a high duty ratio of on-time:off-time, for controlling the first valve V1 to have a large aperture (e.g., almost completely open). Fig. 10b may illustrate a second example of the control signal VCS1 having an approximately 50% duty ratio of on-time:off-time, for controlling the first valve V1 to have a medium aperture (e.g. approximately half-way open). Fig. 10c may illustrate

a third example of the control signal VCS1 having a small duty ratio of on-time:off-time, for controlling the first valve V1 to have a small aperture (e.g., almost closed). The control unit 26 may control the duty ratio of the first control signal VCS1 to be substantially continuously variable, or to have a predetermined number of quantized values. The frequency of the first control signal VCS1 may be between 100 Hz and 1000 Hz. Depending on the frequency, a shutter (not shown) of the first valve V1 may either physically oscillate between the fully open and closed states in accordance with each pulse of the control signal VCS1, or the shutter may effectively hover between the fully open and closed states, at a mean position determined by the duty ratio of the control signal VCS1. A pulsed valve may be any of less expensive, more reliable, and/or more durable than an equivalent servo driven valve.

Variable flow control of the first valve V1 (either by using a pulsed valve or a servo driven valve) may provide additional advantages. A gradual start (or "soft start") of the freeze cycle 36 may be effected by gradually increasing the fluid pressure applied at the inlet side 12a of the cooling device, instead of abruptly applying full pressure to the inlet side 12a in the forward direction. A gradual increase in pressure may reduce the risk of blockage at the orifice 14 by avoiding an abrupt pressure wave that could force dust or other foreign matter on the inlet side 12a to be driven into the orifice 14.

Furthermore, the control unit 26 may be configured to determine an optimum state of the first valve V1 that may optimise the use of the refrigerant fluid. The control unit

26 may be responsive to the signals from the second pressure sensor P2 and the flow rate sensor F to control the first valve V1. For example, the fluid use may be optimised to achieve a flow rate that produces an adequate cooling effect while consuming fluid efficiently. Alternatively, the fluid use may be optimised to achieve a maximum cooling effect.

A further advantage of a variable flow of the first valve V1 may that the first valve V1 may be controlled to provide a modest pressure level of refrigerant fluid, for performing a purge in a forward direction through the cooling device 12. For example, a forward purge may be performed by closing the second and third valves V2 and V3, opening the fourth valve V4, and opening the first valve V1 partly. The first valve V1 may supply modest pressure fluid to the inlet side 12a of the cooling device, and the fluid may vent from the outlet side 12b of the cooling device via the fourth valve V4 and the flow rate sensor F to the exhaust port 22. A modest pressure may not generate significant cooling within the cooling device 12, and so the forward purge may not generate noticeable or undesirable cooling. The flow rate sensor F may be used to monitor the state of flow of the fluid, and to detect an occurrence of a blockage at the orifice 14. Should a blockage be detected, then the unblock mode 59 may be invoked to try to clear the blockage before the cooling device 12 may be used.

Although variable flow control of the first valve V1 may be preferred, in an alternative form the first valve V1 may be a straightforward open-closed valve, similar to the other valves V2-V8.

It will be appreciated that the present invention, especially as described in the preferred embodiment, may provide significant advantages in terms of reducing blockage of a cooling device, and/or automatically unblocking a blocked cooling device, and/or automatically detecting fault conditions, and/or simplifying operation of the cooling device.

An apparatus may be disclosed herein for supplying a refrigerant fluid to a cooling device, such as a cryosurgical probe. The apparatus may include any or all of the following features: An arrangement of valves may control the supply of fluid to and from the cooling device. Fluid may flow in a forward direction through the cooling device for generating cooling by expansion of the fluid in the cooling device. The apparatus may execute a programmed sequence of cooling and heating cycles automatically. Backflushing of the fluid may be used for clearing contaminants from the inlet side of the cooling device. A pulse width modulated control signal may be used to control one of the valves to have a variable effective aperture. A flow rate sensor may detect the flow rate through the cooling device. The detected flow rate may be used to detect an occurrence of a blockage and/or for controlling the fluid supplied to the cooling device. A blockage may be cleared by automatic backflushing.

Although certain features of significance may have been defined herein and/or in the appended claims, the Applicant claims protection for any novel feature of combination of features described herein and/or illustrated in the drawings whether or not emphasis has been placed thereon.